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Solar Energy at Sandia National Laboratories

Sandia National Laboratories is operated as a multiprogram research and development organization for the US Department of Energy (DOE) under a no-fee, no-profit contract by Sandia Corporation, a subsidiary of Western Electric. The laboratory in Albuquerque, New Mexico, employs some 6800 people; the one in Livermore, California, about 1000. Another 100 Sandians operate Tonopah Test Range in Nevada.

Sandia has traditionally emphasized engineering research and development in nuclear ordnance design. In recent years our mission has expanded to include energy research and development. Energy programs now account for about 30 percent of our work. We also undertake assignments for other federal agencies, particularly the Department of Defense (DoD) and the Nuclear Regulatory Commission (NRC). Our solar projects are authorized and funded by the DOE.

This publication was prepared for the Managers of Solar Energy Projects by the Information Services Directorate at Sandia National Laboratories, Albuquerque, NM 87185, May 1981.

Cover: Abrupt increases in the intensity of the emission of superhot hydrogen, calcium, helium, and other elements from the lower atmosphere of the sun produce solar flares like this spectacular display. Erupting near the region of a sunspot, matter is projected outward from the sun's surface as far as 800,000 kilometres at velocities thought to be as great as 320 kilometres per second.

Sandia National Laboratories—Albuquerque, NM

Sandia
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Laboratories

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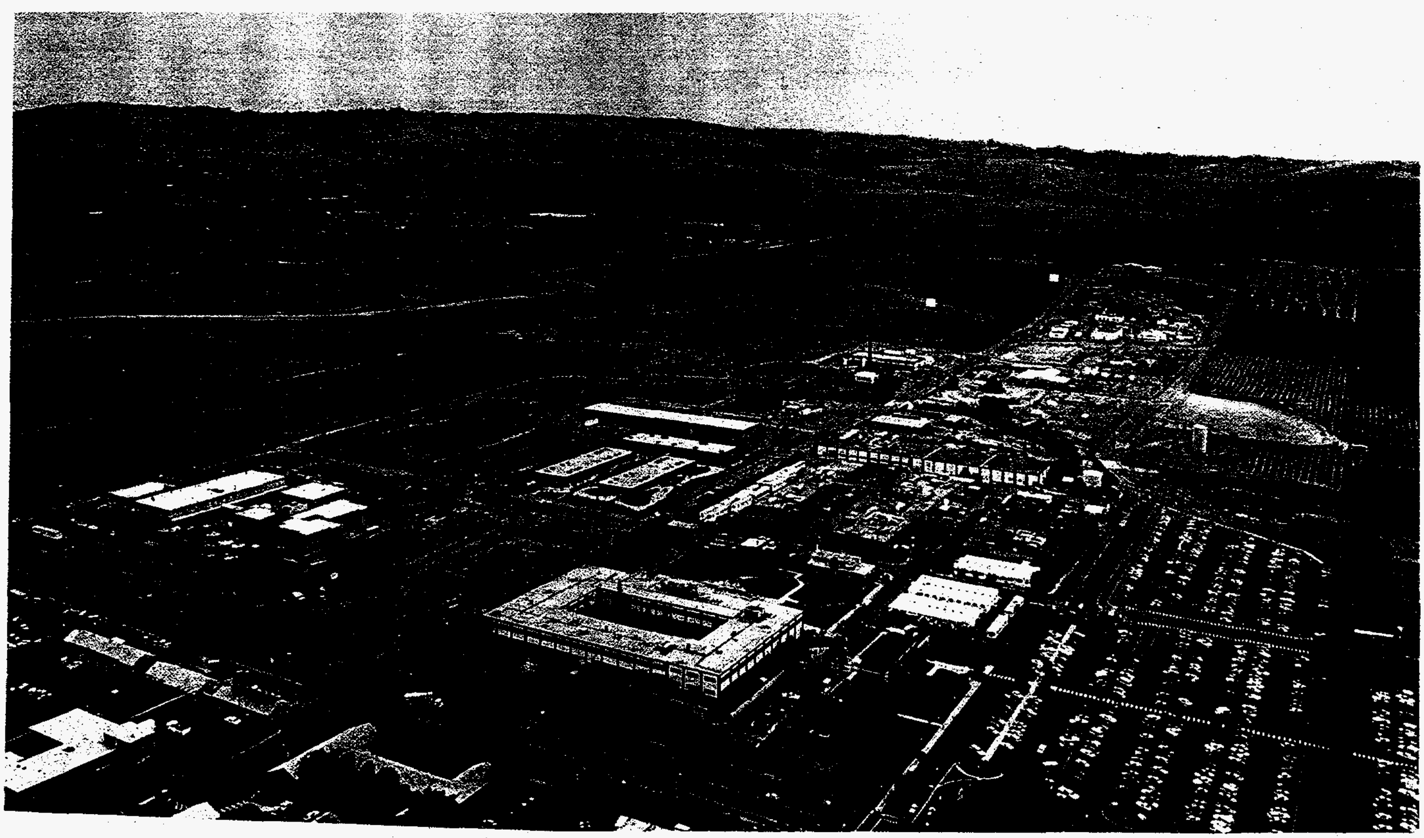

Solar Energy at Sandia National Laboratories

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Introduction

Each day in the United States, the solar radiation — the sunlight — that reaches the surface of the earth makes available more than 100 times the total energy we need to meet all our present needs. The problem is how to harness it.

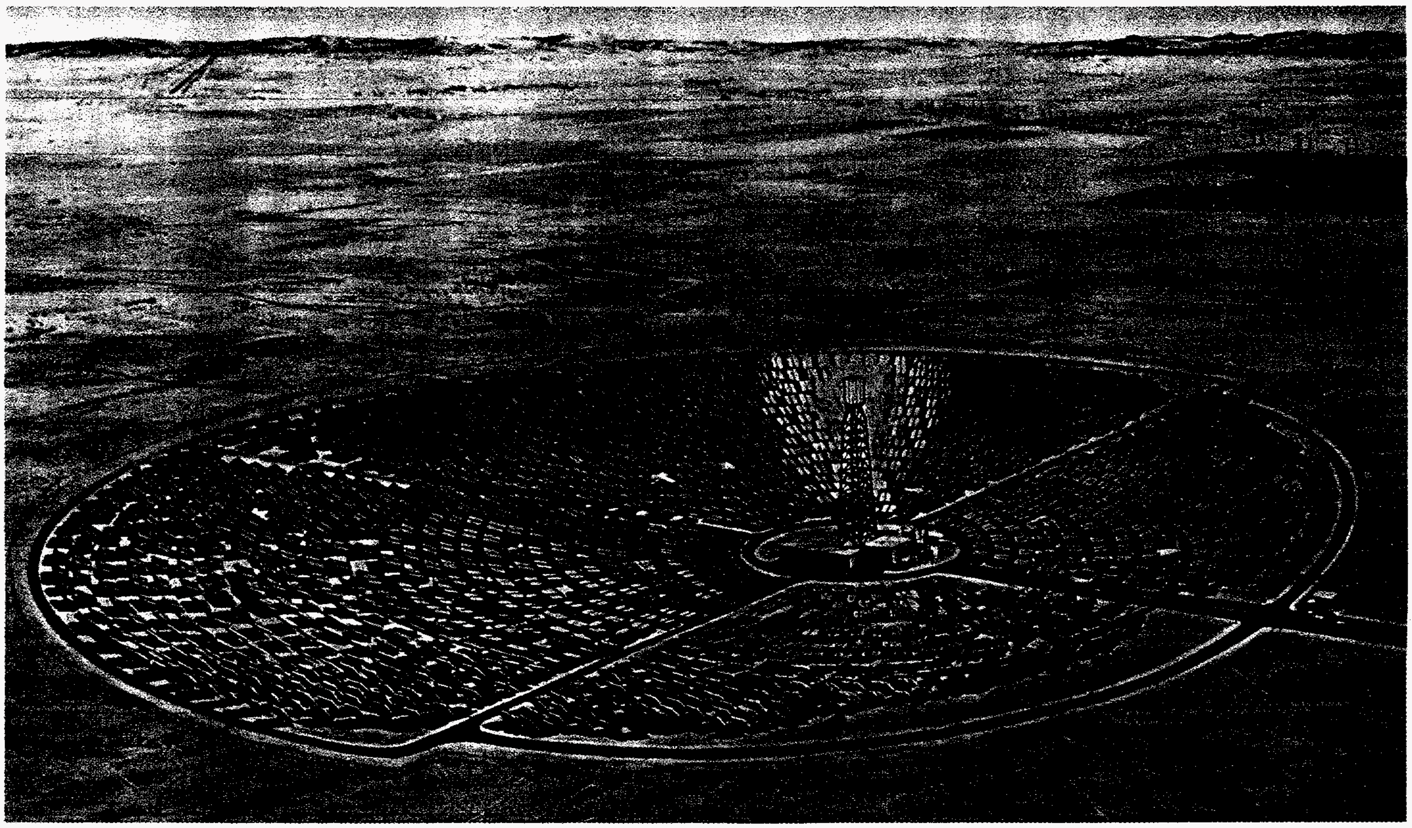
Basic concepts for using the energy of the sun have been known for centuries. The challenge today, the goal of the Department of Energy's National Solar Energy Program, is to create the technology needed to establish solar energy as a practical, economical alternative to energy produced by depletable fuels — and to use that solar-produced energy in a wide variety of applications.

To assist the DOE in this national effort, Sandia sponsors industrial and university research and development, manages a series of technical programs, operates solar experimental facilities, and carries out its own scientific and engineering research. Our own projects involve long-range, technically difficult solar-energy collection and conversion systems — problems that best match the capabilities we've developed over the years in our nuclear ordnance design projects.

New knowledge and information about solar energy are as much a product of our work as operating systems. Both the DOE and Sandia feel it is important to make this knowledge available. We transfer much of this new technology through direct contracts to industry, through publications and workshops, and through public briefings and tours. We also sponsor a resident engineer program that enables representatives of industry to work side by side with our technicians and engineers.

This booklet describes our projects, our technical objectives, and explains how our experimental facilities are used to find the answers we're seeking. Prospective participants from companies involved in solar-energy development or applications should find it especially useful since it outlines broad areas of opportunity. Principal contacts for each solar-energy research program are listed on the last page of the booklet.

Making productive use of the sun's vast energy potential is a matter of deep concern to us all. We solicit your comments on our solar-energy projects — their objectives, approach, priorities, pace, and activities. Suggestions for improvement are always welcome.



Artist's sketch of the Barstow central receiver pilot plant — the largest of its type in the world

Central Receiver Technology

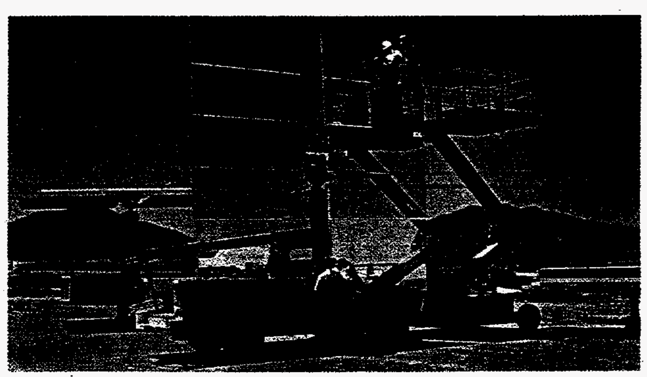
The basic central receiver concept is a simple one, involving the use of a large field of individually steered tracking mirrors called heliostats to reflect the sun's rays onto a receiver mounted atop a tall tower. In the receiver, a highly concentrated solar flux heats a fluid that either powers a conventional turbine to produce electricity or supplies industrial process heat. This fluid can be transferred to a heat-storage system for later use when sunlight is not available.

Though no scientific breakthroughs are required, the central receiver program demands much in the way of new technology. Sandia's projects, directed by our Livermore laboratory, include development of low-cost special materials, better reflector and receiver designs, and improved thermal storage systems. A primary goal of the project is transfer of this technology to private industry.

The Central Receiver Program

A major part of the central receiver program is the design and construction of a solar pilot plant with an electrical capacity of 10 megawatts (10 MWe) in the Mojave Desert near Barstow, CA. A field of 1800 heliostats, each with an area of 42 square metres, will reflect solar radiation onto a receiver on top of a tower 86 metres high. Southern California Edison will operate the plant, which can furnish power for a city of 10,000. It will be operational in late 1981.

Sandia is also providing technical assistance to several international solar central receiver projects. We are helping design and construct a 500-kilowatt central receiver plant at Almeria, Spain, for example. In Italy, we are involved in a project



Prototype heliostats for the Barstow plant to integrate central receiver electrical generating plants into the country's electrical grid.

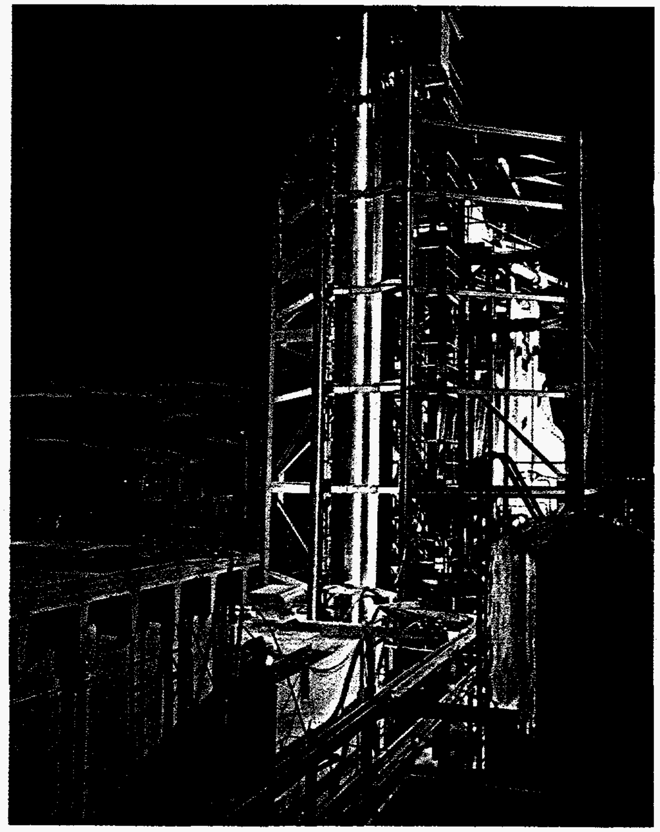
Component Development

Private industry, through competitive bidding, is doing most of the development of central receiver system components. Sandia manages these projects and contributes technical expertise and evaluation of specific designs. We also develop components to fill gaps in the program and initiate analyses and experiments to assess alternatives.

Because the heliostat field represents one-third to one-half the total cost of the central receiver plant, an aggressive program is under way to develop the most economical designs. Nine companies have completed conceptual designs and seven prototypes have been built, two with private funds. Extensive testing has been completed on preproduction heliostats for the Barstow plant, and production of the units is under way. Four second-generation heliostat designs are scheduled for comparative testing in 1981.

Receiver Designs

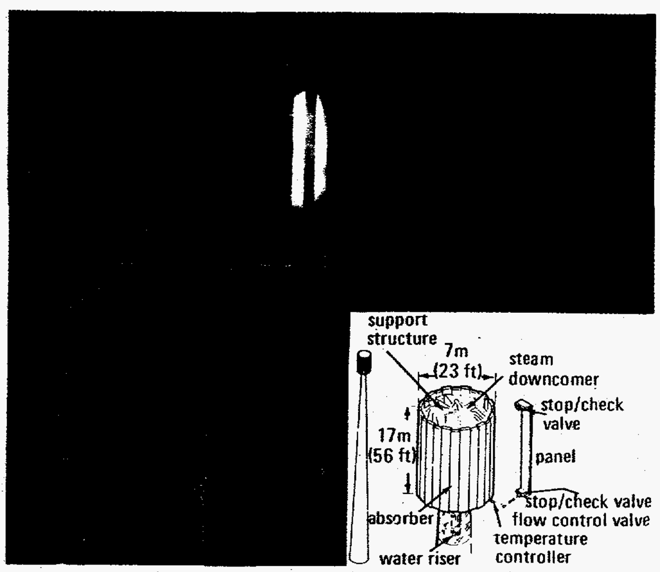
Heat-transfer fluids — water/steam, molten salts, liquid metals such as sodium, and gases such as air and helium — are under investigation for use in the central receivers. Water/steam has been selected for near-term applications, and several large-scale cavity and external boiler experiments have confirmed this approach. In one such experiment at Sandia's Central Receiver Test Facility, a single panel of the Barstow receiver, with 70 parallel once-through boiler tubes, was used to demonstrate the operation of all the



The five-tube test experiment under way at the Radiant Heat Facility, Albuquerque

panel's elements. A complementary experiment with five parallel boiler tubes studied the thermo-hydraulic behavior of the once-through boil-to-superheat feature of the Barstow receiver.

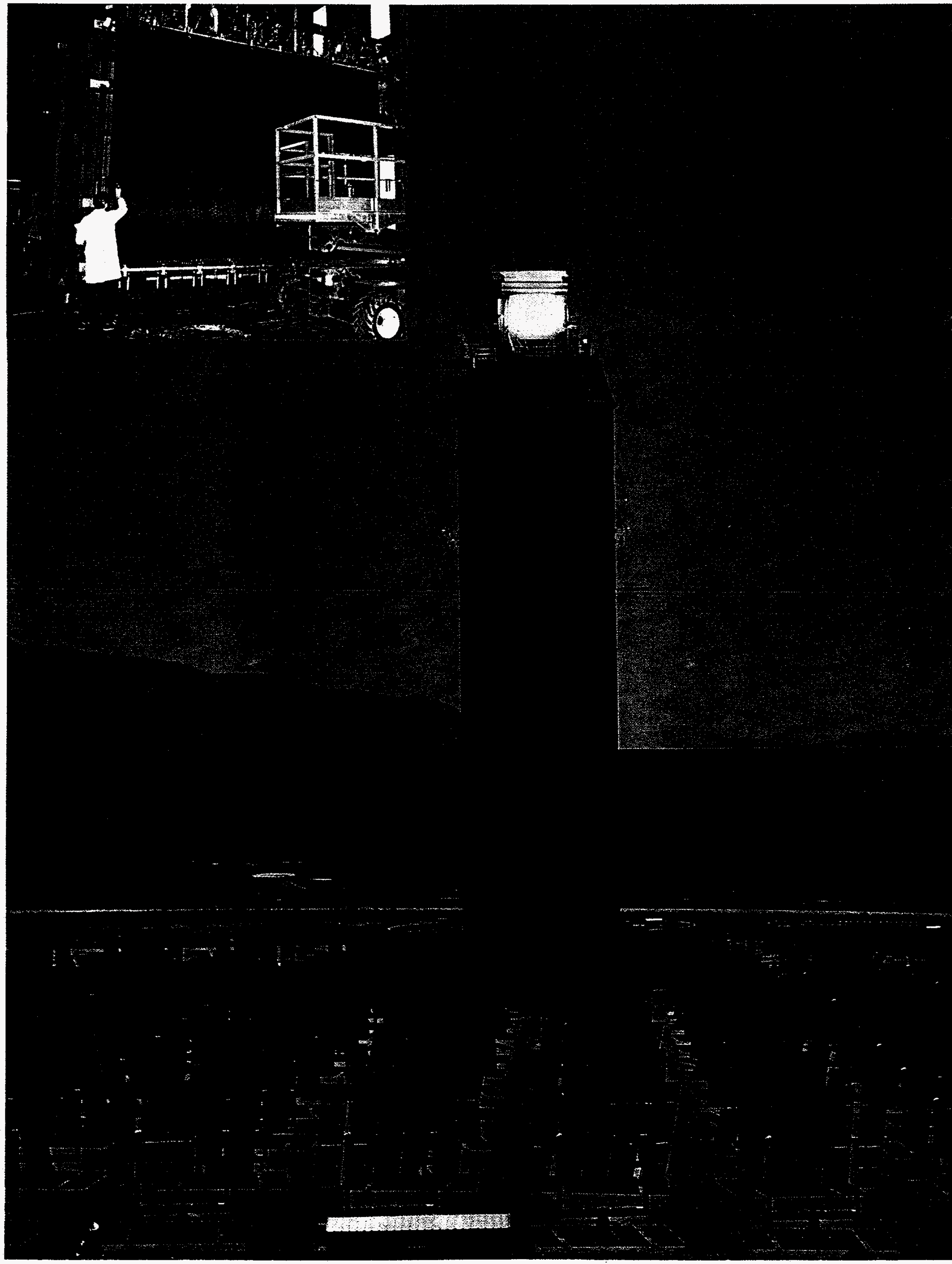
Molten nitrate salts and liquid sodium are attractive receiver coolants for advanced central receivers. Either candidate could significantly reduce the cost of central receiver systems. The main advantages of molten nitrate salts and liquid sodium are increased heat transfer and storage potential, and the ability to reheat steam between operational stages of the turbine. One molten-salt large-scale experiment in design and operation was completed at the CRTF in 1980; a sodium experiment is planned for 1981. The resulting data will be supplied to the design teams competing for repowering and process-heat application programs.



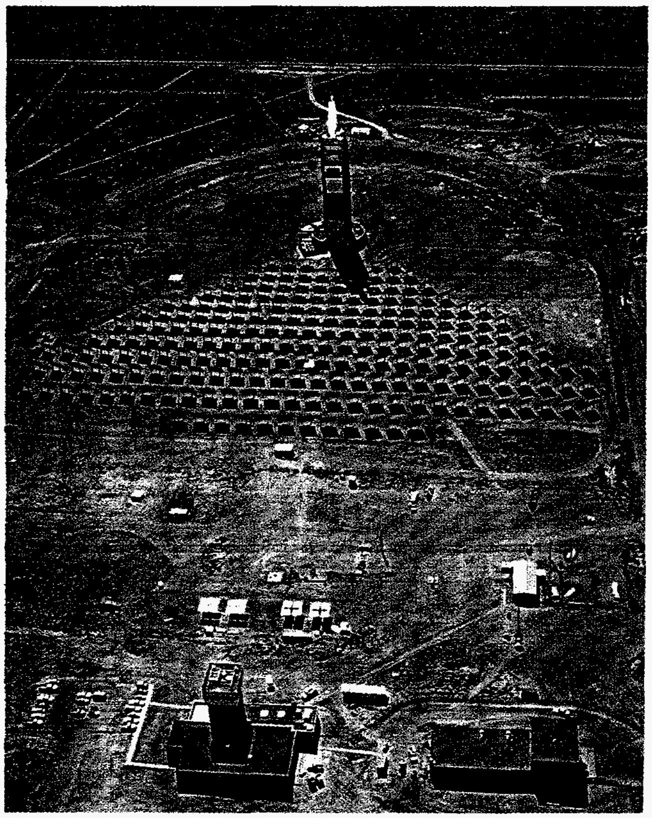
A closeup of the CRTF tower. Inset shows the structure of the receiver

Central Receiver Test Facility (CRTF)

The CRTF at Sandia in Albuquerque was built to support the central receiver program. The first series of experiments emphasized receivers and heliostats proposed for the Barstow plant. Ongoing experiments include advanced central receiver designs, Electric Power Research Institute's receiver models, high-intensity photo-



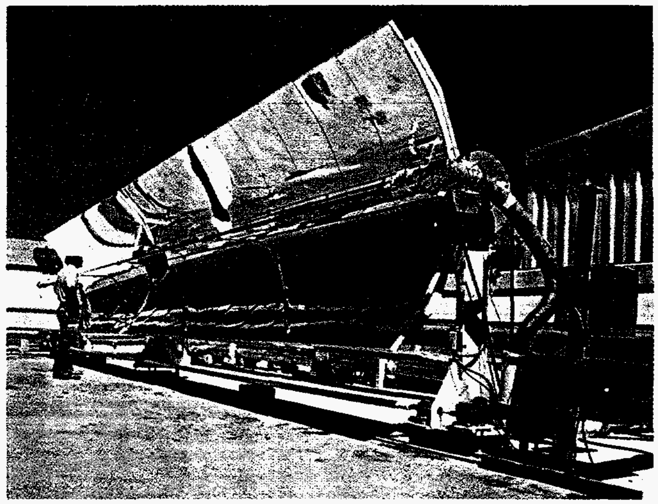
Molten-salt experiment in operation at the CRTF. Inset shows the test panel before erection onto the tower



Located at Albuquerque, NM, the Central Receiver Test Facility provides a solar thermal testing capability up to 5 MW thermal. Here the heliostats are positioned to reflect concentrated sunlight onto a panel high atop the tower

voltaic devices, advanced heliostat designs, and material/chemical properties and processes. The CRTF consists of 222 focusable, individually controlled heliostats, each with 37 square metres of reflective surface area. These heliostats collect and concentrate more than 5 million watts of thermal solar power with a peak flux level of 2.5 megawatts per square metre. (Concentrators can increase the flux level to ~10 megawatts per square metre over an area of 0.05 square metre.) The heliostats can be positioned north of the 61-metre-tall test tower, or in a circle around it. The tower has north-facing test bays at heights of 36, 42, and 48 metres, and test bays and knockout panels facing east and west at heights of 36 and 48 metres.

DOE's long-range goal for the CRTF is to use it as a national experimental resource both to develop solar thermal technology and to explore the technology for other solar energy conversion processes. Experienced engineers are available at the CRTF to assist all experimenters. A Users Association has been established to assure maximum effective use by researchers throughout the country. Interested parties are encouraged to contact CRTF management or the STTF Users Association concerning use of the facility, experimental capabilities, and current status.



Engineering prototype parabolic trough

Line-Focus Thermal Technology

Each year about 15 percent of our nation's total energy is consumed in the form of industrial process heat at temperatures below 300°C. Line-focus solar concentrators are particularly useful for generating heat in the range from 100° to 350°C. This category includes any collector (a parabolic trough, for example) in which reflected sunlight is focused onto a linear receiver. Sandia manages development of this technology for the DOE through industrial contacts.

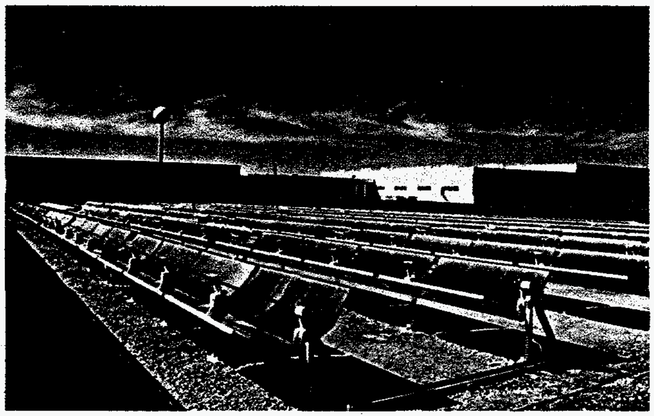
Line-Focus Concentrator Program

Major objectives of the line-focus concentrator program are

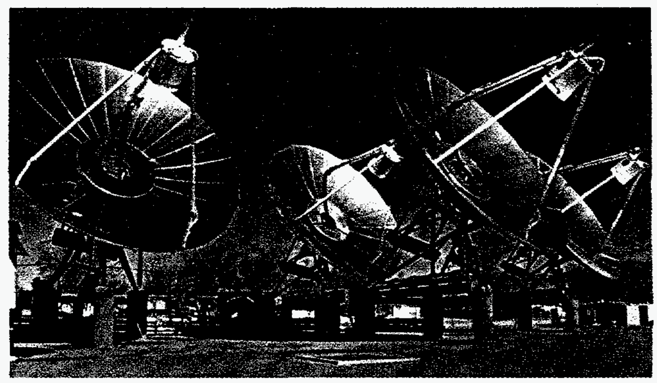
- To develop an understanding of the value and potential of line-focus concentrator technology
- To assist in developing the technology of the associate industry
- To disseminate sufficient information to allow public decisions on the technology to be made with high confidence

Strategies to meet these objectives are twofold: (1) improving performance and reliability at the component, subsystem, and system levels, and (2) reducing the cost of manufacturing and installing the systems.

The line-focus concentrator program is directed primarily at solar applications that make use of direct heat. One example is the industrial process heat (IPH) system built at the Johnson and Johnson plant in Sherman, TX, where 1070 square metres of parabolic-trough collectors provide steam at 174°C for a gauze-bleaching



A solar process-heat application in Sherman, TX



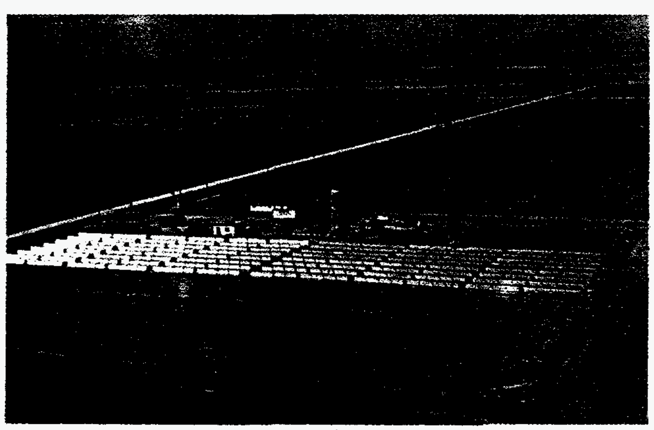
Prototype parabolic-dish collectors designed by GE for the Shenandoah, GA project

process. Other direct applications of solar heat include enhanced oil recovery, commercial heating and cooling, and boiler feedwater preheating.

Line-focus concentrator systems can generate thermal energy efficiently at temperatures up to 350°C. Heat engines, to produce shaft power operating from such systems, are 15 to 30 percent efficient. A pioneer full-scale solar-powered irrigation system was built in 1977 in the Estancia Valley near Willard, NM. In this small system, 1300 square metres of parabolic-trough collectors operated an organic Rankine-cycle (ORC) turbine to drive an irrigation pump. The water supplied irrigated 120 acres.

A larger deep-well irrigation project based on second-generation technology was completed in 1979 at Coolidge, AZ. This project, which uses a new ORC turbine design, contains 2140 square metres of collector area and generates 150 kilowatts of electrical power to supply a local grid.

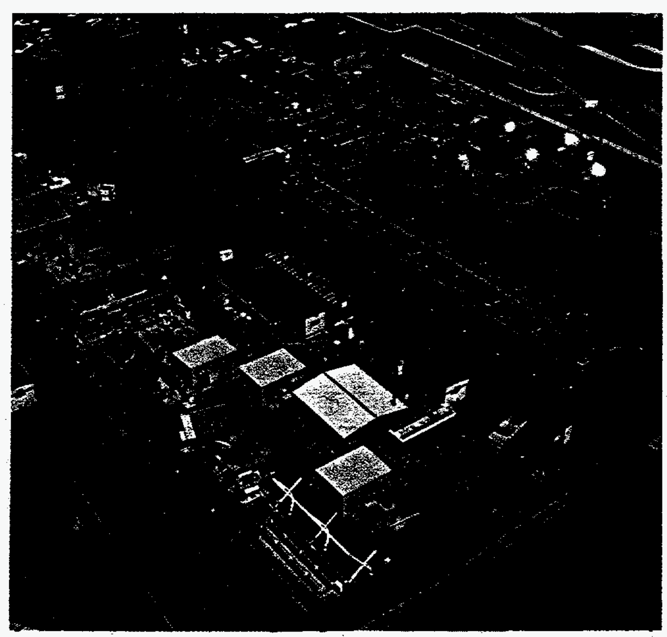
If the heat rejected from a turbine can be recovered and used for some purpose, as much as 60 to 80 percent of all heat collected by the system can be used effectively in a process called cogeneration. Another term is "total-energy system." This concept, first demonstrated at Albuquerque's Midtemperature Solar Systems Test Facility (MSSTF) has since been applied in a design for a knitwear manufacturing plant at Shenandoah, GA. When construction is complete, this collector field will supply 2.7 megawatts peak to the total-energy system, which will in turn supply 400 kilowatts of electric power and 614 kilograms per hour of process steam at 175°C, and low-quality heat for space heating and air conditioning. The design uses a parabolic-dish collector system that collects thermal energy at 400°C. Another major emphasis, the Modular Industrial Solar Retrofit Project, began in 1980. Initial goals are to reduce the cost of installing parabolic-trough collectors and to improve the overall system reliability of available hardware.



Deep-well irrigation system at Coolidge, AZ

Component and Subsystem Technology Development

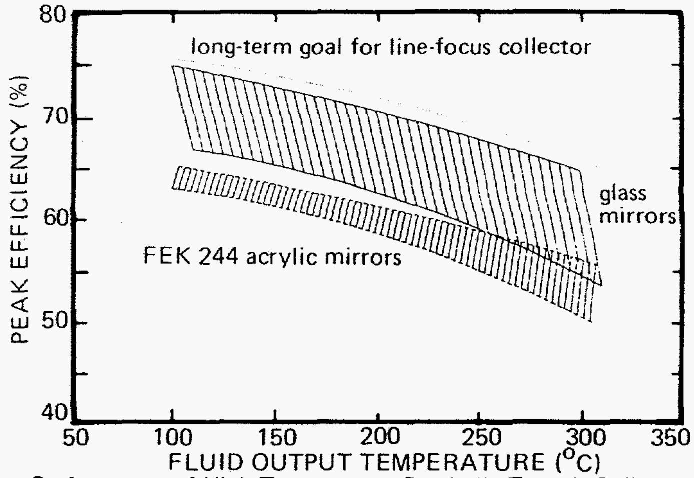
Much of the technology developed in this program is evaluated or qualified in a realistic operating environment at the MSSTF in Albu-



Aerial view of the Midtemperature Solar Systems Test Facility (MSSTF), Albuquerque

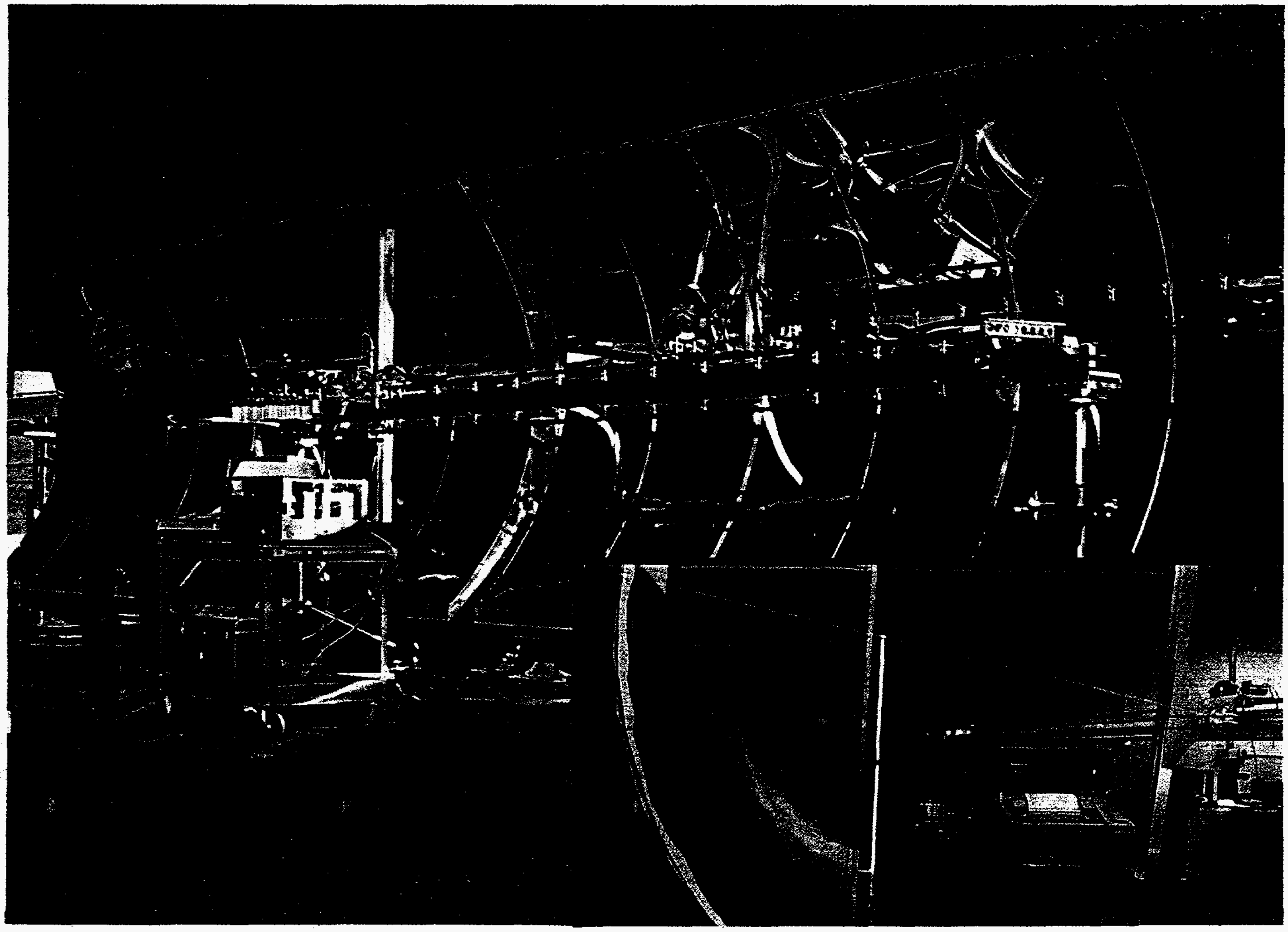
querque. Work at this facility focuses on evaluating commercial solar components such as advanced reflectors with the potential for high production rates and low materials requirements, advanced tracking and control systems, receivers, drive systems, and foundations. The availability of special-purpose facilities, such as Sandia's environmental test chambers, has allowed systematic evaluation of the potential reliability of many structural designs. Instruments such as a portable reflectometer and a laser-ray tracer have also been developed and constructed for use in characterizing reflector subsystems.

Engineering prototypes have already been built that convert more than 60 percent of the sunlight falling on a collector to thermal energy at 315°C. Many industrial manufacturers of parabolic troughs are working on their own designs to meet or exceed this demonstrated performance and to enhance their prospects for manufacturing troughs at competitive prices.



Performance of High-Temperature Parabolic-Trough Collectors

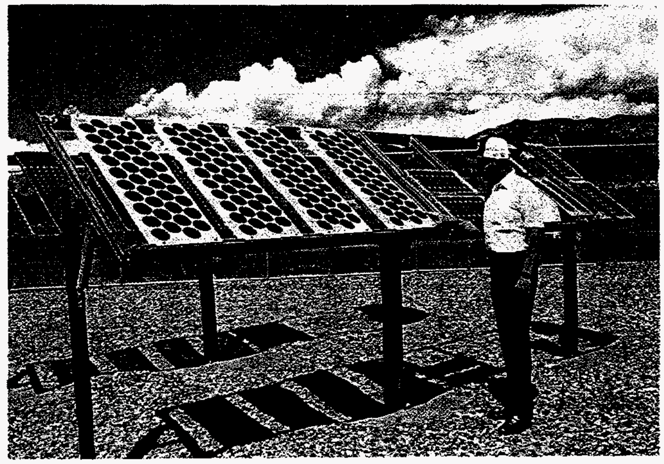
Performance of various prototypes tested at the Collector Module Test Facility, Albuquerque vs long-term goal set for line-focus collectors



Laser-ray tracer

Photovoltaic Systems Technology

Photovoltaics is the direct conversion of sunlight to electricity without an intermediate step involving heat. Photovoltaic cells produce electricity by the absorption of sunlight in thin layers of a semiconductor material such as silicon (see figure). These cells were invented at Bell Laboratories in the 1950s and are used today in the space program to provide power for hundreds of satellites. Such power systems are finding increased applications in remote areas of the world where conventional sources of power are not available.



A photovoltaic collector array made up of 1-sun cells

The Photovoltaic Program

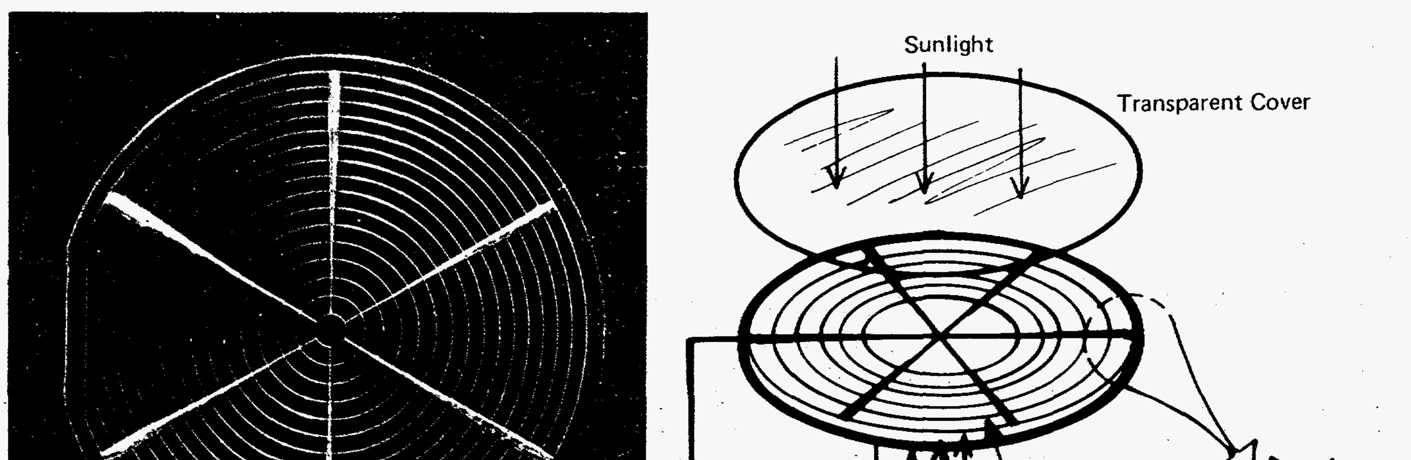
Sandia has a leading role in the national Photovoltaic Program, a program that seeks to develop industrial capability for producing reliable, low-cost photovoltaic (PV) power systems for widespread applications in residences, commercial buildings, and industry. Tasks include developing concentrator array technology, designing power systems, and balance-of-system engineering.

Concentrator Array Technology

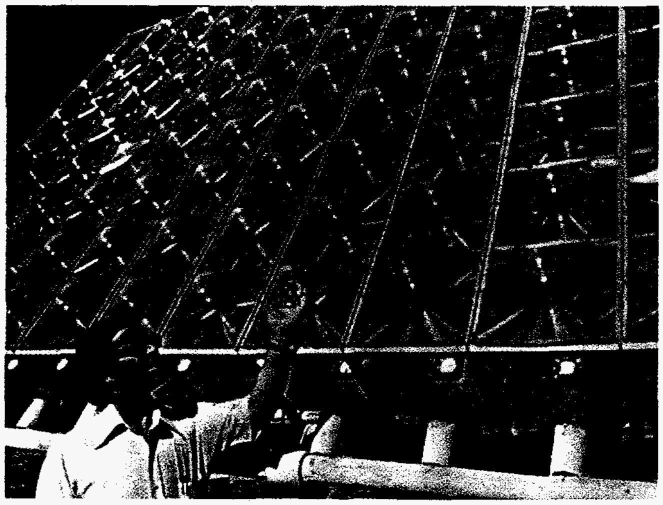
The heart of any PV power system is the cell array that converts sunlight to electric energy. Most arrays now use groups of cells wired together in a module designed for placement in direct sunlight. Cell manufacturers, with DOE assistance, are developing new production techniques to reduce costs per watt of these modules from $7 to about $0.70. The key cost element is the individual cell.

An alternate way of reducing costs is to substitute inexpensive mirrors or lenses that concentrate sunlight onto a fewer number of cells. The Sandia-designed 1000-watt prototype explored initial feasibility of the alternate method; it uses molded plastic Fresnel lenses to concentrate sunlight at a brightness of about 50 suns upon a specially designed silicon cell. Industry later reproduced both a special cell design and a weatherized 2.2-kilowatt array. One-hundred sixty of these arrays will be used to power a town in Saudi Arabia under US-Saudi agreement.

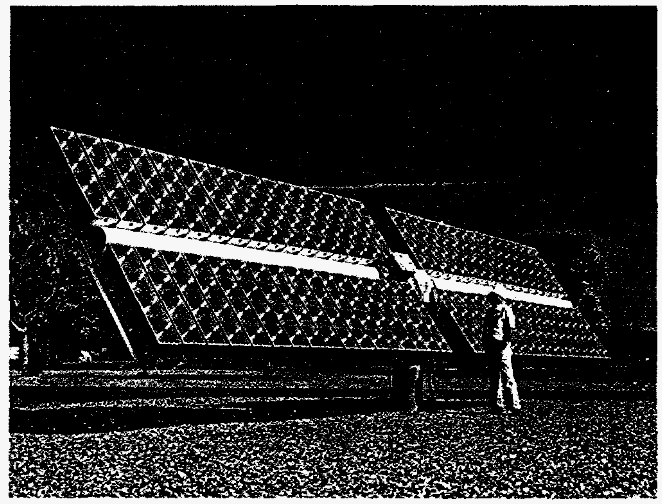
In addition to the possible cost reductions, two technical attributes make concentrator PV



1-sun photovoltaic cell. Artist's drawing shows construction of cell



1000-watt photovoltaic system prototype designed by Sandia

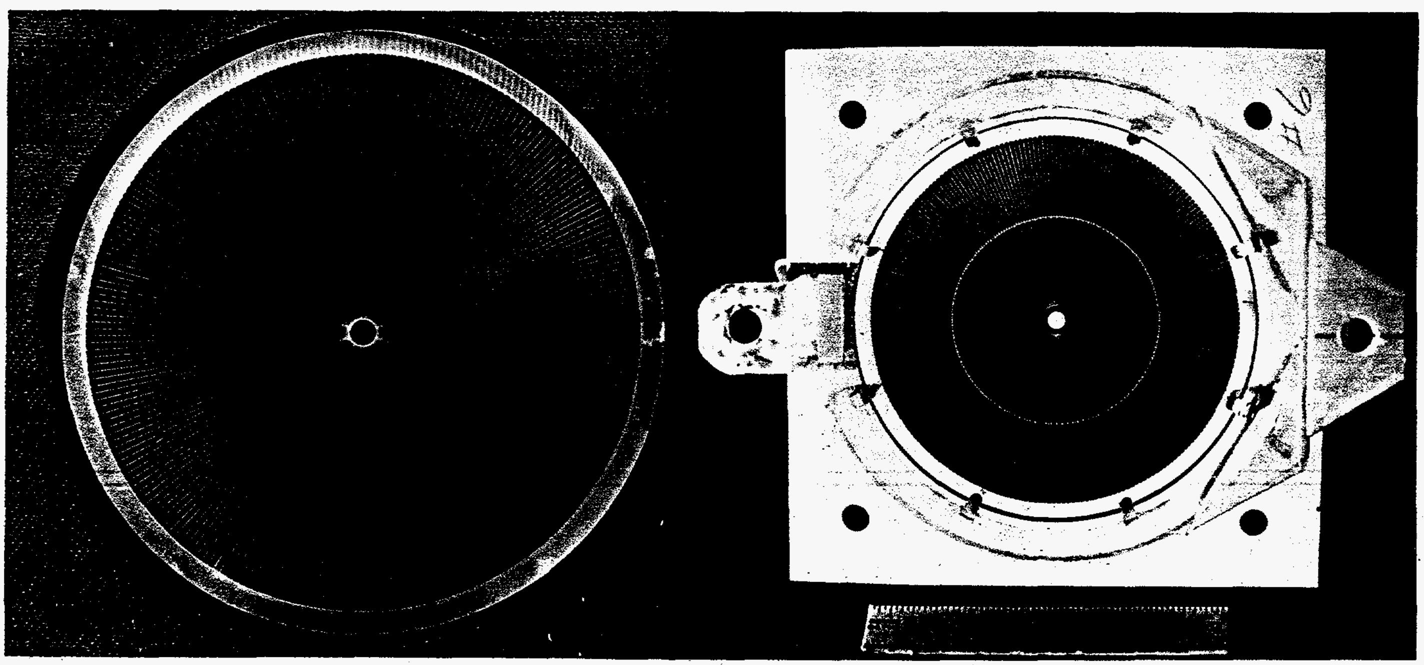


2.2-kilowatt array designed by Martin Marietta for Saudi Arabia

systems attractive. The first is the prospect for significantly higher efficiency of sunlight-to-electric conversion. Doubling the illumination level on a cell results in more than twice the production of electric power. Concentrator intensities of more than 1000 suns are possible, with potential and actual conversion efficiencies listed in Table 1. For comparison, flat-panel modules under 1-sun illumination operate in the efficiency range of 8 to 12 percent.

The second technical attribute of interest is heat energy. The use of concentrator arrays makes it possible to collect a large amount of heat energy together with the electric power. Many potential PV users need the thermal energy, and its value can improve the economic breakeven point by a factor of 2. One of our objectives is to demonstrate a technical capability to make concentrator modules at $2.80 per watt. This could be done if component parts like that shown in the figure were procured from industry in moderate mass-production quantities.

Sandia has constructed a Photovoltaic Advanced Systems Test Facility dedicated to testing with real sunlight, but under well-instrumented conditions. We are using the facility to explore the latest concentrator photovoltaic arrays developed by industry and by Sandia engineers, as well as to qualify experimental hardware for major offsite system experiments. Power conditioners, dc-to-ac inverters, battery electric energy storage, and utility interface switchgear can also be tested.



a. A Sandia-designed silicon solar cell 5 cm (2 in.) in diameter designed for illumination levels of 50 to 100 suns and operating temperature to 100°C. Rated efficiency is 15.5%.

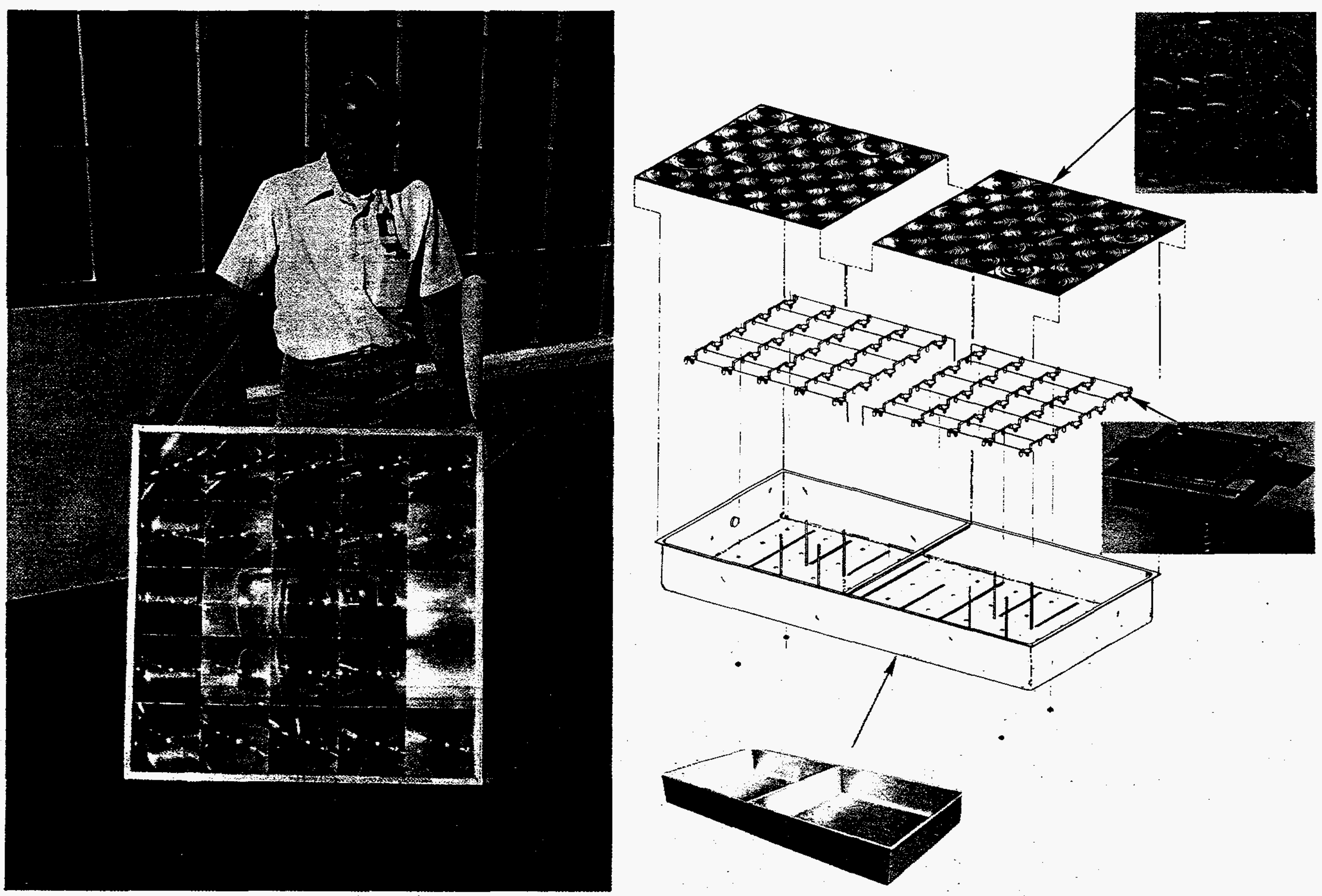
b. Silicon cell for the Martin Marietta photovoltaic array by Applied Solar Energy Corporat on

TABLE 1

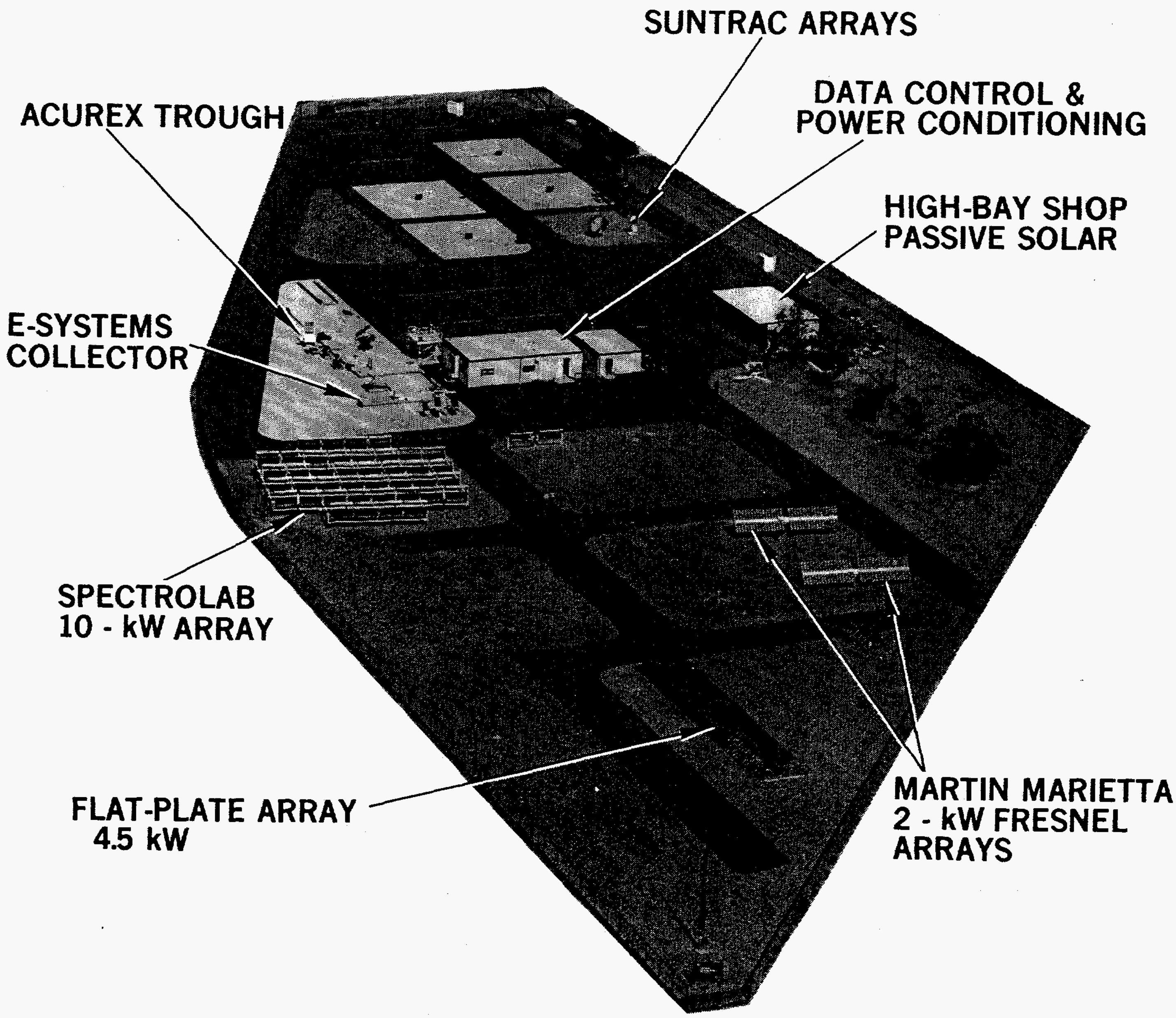
CONVERSION EFFICIENCIES OF
CONCENTRATOR SOLAR CELL TECHNOLOGIES

Cell Technology	Concentration Range	Potential Efficiency (%)	1980 Achieved Efficiency (%)
Silicon			
Horizontal Junction	25 to 100	21	20.4
Vertical Junction	200 to 1000	26	18.5
Single-Junction GaAlAs	500 to 1000	26	23
Multiple-Cell Spectral Separation (GaAlAs—Si)	500 to 1000	30-35	31
Multiple-Junction Stacks (GaAsSb/GaAlAsSb)	500 to 1000	30-40	---
Thermal-Photovoltaic	5000 to 10000	30-40	26

Conversion Efficiencies of Concentrator Solar Cell Technologies



A photovoltaic concentrator "strawman" module designed for low cost

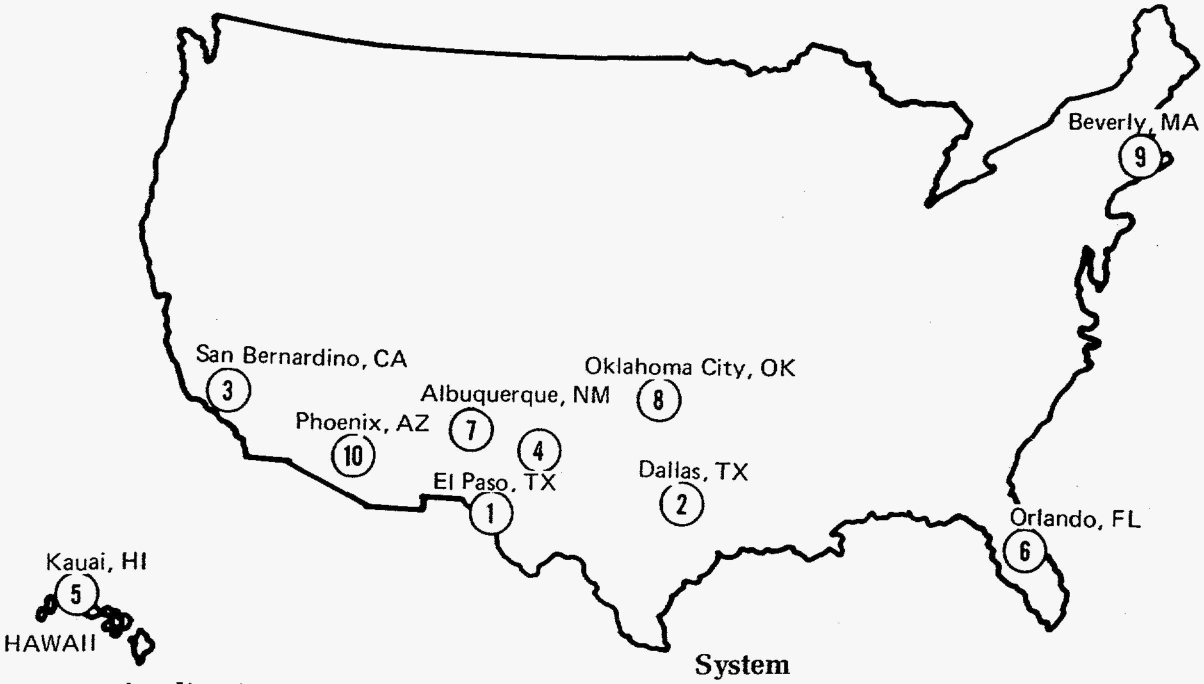


Sandia's Photovoltaic Advanced Systems Test Facility

Power System Design and Definition

PV power systems may vary in size from a few watts to hundreds of megawatts and can be used in many ways. For example, they can power isolated electrical loads in stand-alone systems, or interconnect with local electric grids to generate electricity for widespread utility systems. They can be located onsite at the point of use for the electricity, or in large fields remote from use. Data are being gathered on load requirements, energy cost and availability, power quality and reliability, market potential, siting factors (including land use and grid interconnections), financing, and ownership for each class of potential major use. The data will lead first to the required cost and performance characteristics of economically competitive PV power systems, and eventually to a set of preferred system designs and simplified design methods.

Work completed so far does not show any strong technical preference for residential, central station, or load-center applications of intermediate



	Application	System Size (kWp)	Contractor
1	Utility computer power	20	New Mexico State University
2	Airport power system	27	E-Systems
3	Industrial park	35	San Bernardino Community Development Corp.
4	Professional office building	47	BDM Corporation
5	Hospital	60	Acurex Corporation
6	Sea World Park	110	General Electric
7	Shopping center	150	Lea County Electric Cooperative
8	Science and art center	150	Science Applications, Inc.
9	High school	150	Solar Power Corporation
10	Airport power supply	225	Arizona Public Service Co.

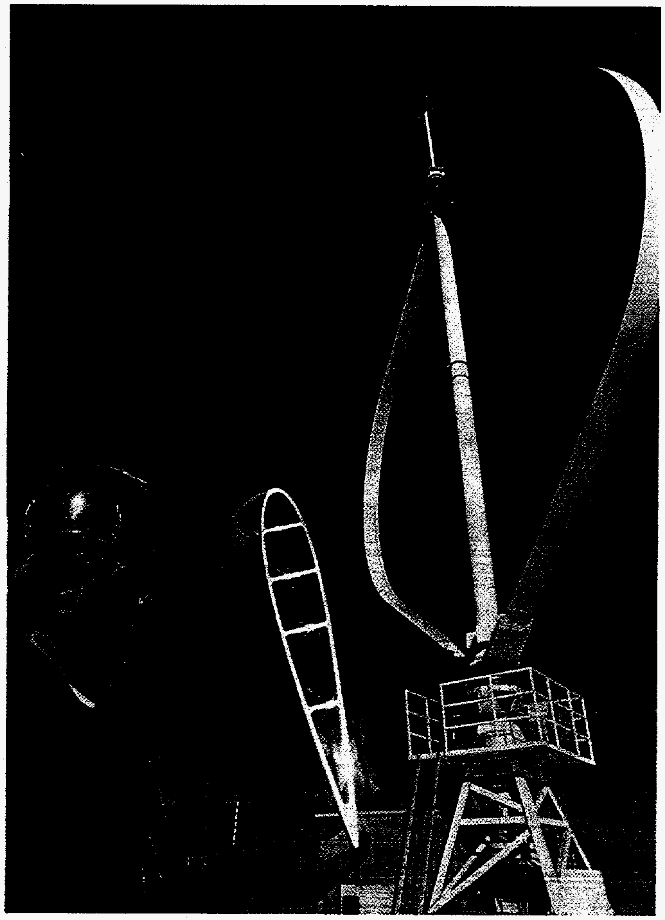
Sites of major DOE/Sandia photovoltaic system application experiments

size. Because intermediate-sized load-center applications do appear to offer some economies of scale as well as favorable aspects of ownership and financing, and good load matching, they were selected for competitive bids leading to a first set of real-world experiments of PV systems. The accompanying figure shows the geographic location of these cost-shared experiments, their industry team, and their particular uses. As technical manager, Sandia assists the DOE in these experiments.

Balance-of-System Engineering

"Balance-of-system" is the name given all activities and hardware that must be added to a factory-delivered PV module to make up an operating power system. Principal items in this system are

- The photovoltaic array, which involves the collector, structures and foundations, site preparation, field wiring and lightning protection, and installation
- The power processor, comprised of the dc-ac inverter, switchgear, and the control building
- Energy storage, including batteries, battery housing, and the charger/regulator
- Miscellaneous elements such as marketing and distribution, design and management fees, sales fees, and interest during construction



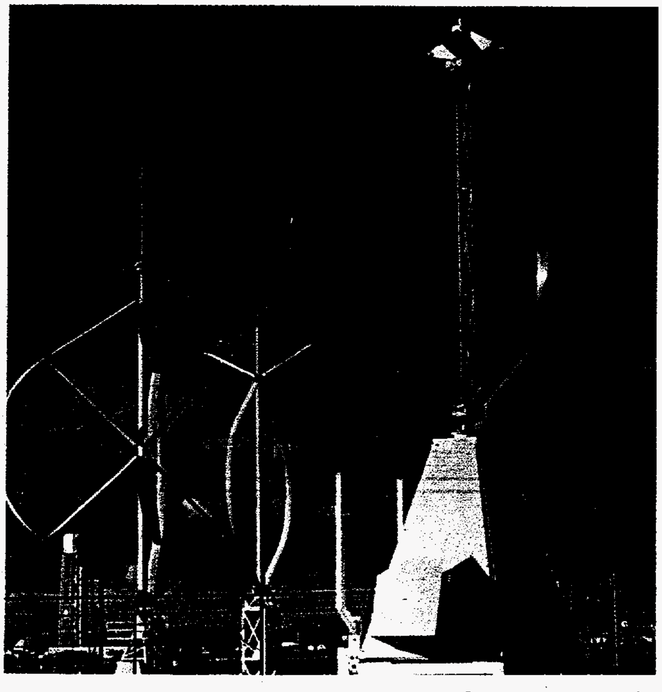
Vertical-axis wind turbine 17 metres in diameter. This research turbine shows a two-bladed design made of extruded aluminum. The Sandian in the foreground holds a cross section of the blade

Sandia is using industrial know-how to develop practical, low-cost, and reliable ways to assemble PV systems. Low-cost mounting methods have been designed and tested. Factory assembly of modules into arrays more easily installed in the field is being studied. Efficient, low-cost power-conditioning units in a range of sizes from 8 kilowatts to several megawatts have been designed, and several of the smaller prototypes built. Utility interface switchgear and electrical protective devices have been designed and tested. The outlook is bright that balance-of-system hardware will be ready for widespread use as expected cost reduction in PV modules is achieved.

Wind Turbine Development

Windmills have been a familiar part of the energy landscape for centuries, from the mills of Holland that pumped away the water and reclaimed low-lying farmlands to the cattle-watering pumps still used in the American West. In 1926, a French inventor, D. J. M. Darrieus, designed an unusual vertical-axis wind turbine (VAWT) that drew scant attention until the 1970s. Revival of interest in renewable energy resources prompted Sandia to begin aerodynamic and structural engineering research in this type machine. The VAWT has several advantages over conventional propeller turbines that may result in lower costs. Its vertical symmetry eliminates the need for yaw controls to turn the machine into the wind. Its power-conversion machinery (gearbox, generator) is at ground level, which permits the turbine rotor to be supported by guy cables instead of cantilevered from a massive foundation. Very significantly, the VAWT is aerodynamically self-regulating in high winds; so no blade-pitch controls are needed to avoid overdriving the generator. Finally, since the cross section of the turbine blade is constant and the blade is attached at both ends, blades can be fabricated by using low-cost fabrication methods like one-piece extrusion. On the negative side, VAWTs are not self-starting, they generally turn at a slower speed (which tends to increase drive train costs), and they have more rotor blade area than propeller machines.

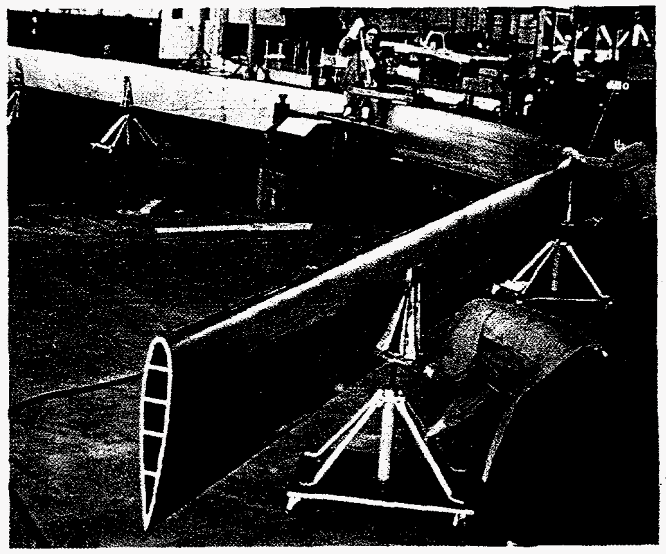
A comprehensive set of computer aids — aerodynamic, structural, design optimization, and test-data processing — have been developed for VAWTs. Documents describing these tools are available for public use. The computer aids have been validated by comparison with test results from the three research VAWTs operated at Sandia. These machines (2, 5, and 17 metres in di-



Three VAWT research machines tested at Sandia. From left to right: 17 metre, 5 metre, and 2 metre ameter) have been used with several blade cross sections and fabrication geometries, many combinations of turbine speed with wind speed, and in tests involving intentional overstress and overspeed.

The VAWT program has been very successful. Our machines performed better than expected, and low-cost parts proved feasible. These technical factors, as well as power cost forecasts ranging from $0.03 to $0.06 per kilowatt-hour, led several companies to begin commercial marketing.

Future VAWT projects will aim at improving technology and lowering the cost of producing energy. We'll be looking for ways to improve blade aerodynamics, reduce structural conservatism, improve transmission efficiencies, and develop low-cost manufacturing processes. Building larger machines will also help them operate more economically. The focus of all these efforts will be a megawatt-sized Mod 6V VAWT. An industry team will be selected to participate in extending VAWT technology into this promising next generation of machines.



A blade for the VAWT: one-piece extrusion of aluminum being bent to shape

VAWT Computer Codes in Use at Sandia

Aerodynamic Modeling

PAREP — Parametric representation of performance; fast-working
SIMOSS — Single streamtube model
DART/DARTER — Multiple steamtube model
VDART 2/3 — Vortex Model, two-thirds dimensional

Structural and Dynamic Modeling

SKEIN — Defines troposkeins under various loading conditions
MARC-H/MGX — Performs static, nonlinear stress analysis and plotting
VAWTDYN — Predicts dynamic turbine response to given initial conditions
TORIP — Predicts torque ripple based on 4 degrees of freedom
DMG — Darrieus model generator, complex design modeling

Economic Modeling

ECON-16 — Predicts cost per kilowatt-hour based on given design; some optimization

Field-Testing Codes

ATSTR — Turbine performance using BINS technique
PCMTS/SATD — Creates time series records from transducers
QUIK — Calculates maximum, minimum, and average blade stresses
SPEC5 — Computes spectral density of time series
TRBTR — Computes torque ripple from time series
RUN17 — Automatic control operation of 17-m turbine

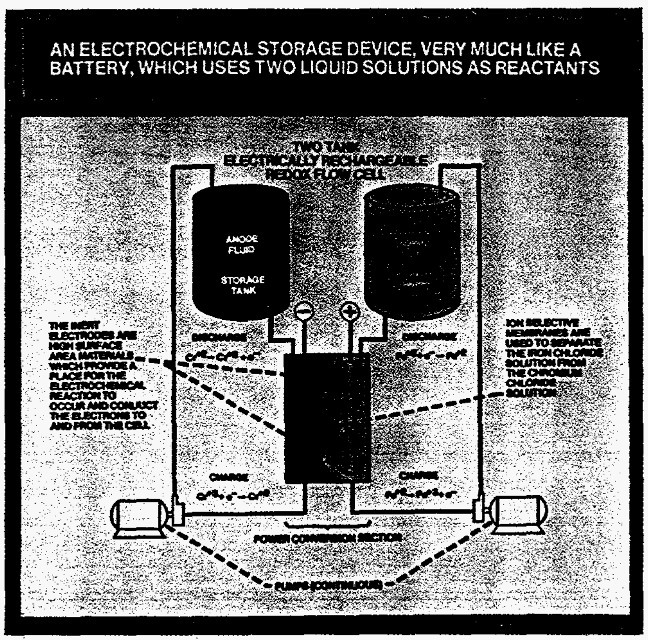
Storage Technology

The application of solar thermal and photovoltaic power systems now being developed can be extended if ways are found to store their energy. Solar power plants can interact with existing power-generating plants in a fuel-saving mode when all conditions are right. But storage is needed to supply power for cloudy days, at night, and during emergencies. An energy storage system can also buffer variations caused by abrupt changes in solar insolation, making it easier to control plant operations.

Thermal Energy Storage for Solar Thermal Applications

Sandia has two application goals for thermal storage technology: (1) to provide first-generation storage subsystems for solar thermal applications that have no such subsystems, and (2) to develop second-generation storage subsystems that perform better and cost less than first-generation subsystems.

Thermal storage technology is now being matched to solar thermal power system requirements for repowering and industrial retrofit, total energy, and small-community system applications. Sensible heat stored in a variety of working fluids and dual-media systems, as well as advanced phase-change or reversible chemical reactions, is being analyzed.



Schematic of the REDOX system. In this system all electrochemical active materials are liquids, not solids. The anode fluid is a solution of chromium chloride, and the cathode fluid is a solution of iron chloride. There are no plating or deplating reactions like those in solid battery electrodes that shorten the life of conventional batteries. Power output in the system is set by the size and number of cells grouped in the power-conversion section. This novel feature allows independent sizing of the amount of system power and energy storage.

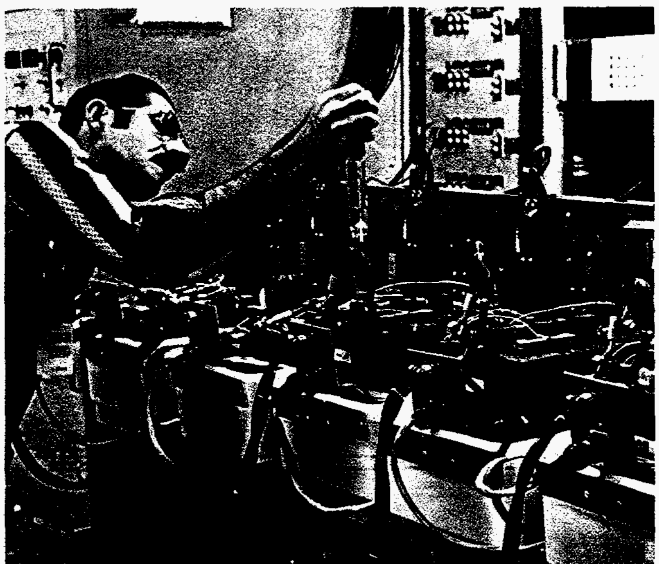
Battery Storage for Specific Solar Applications

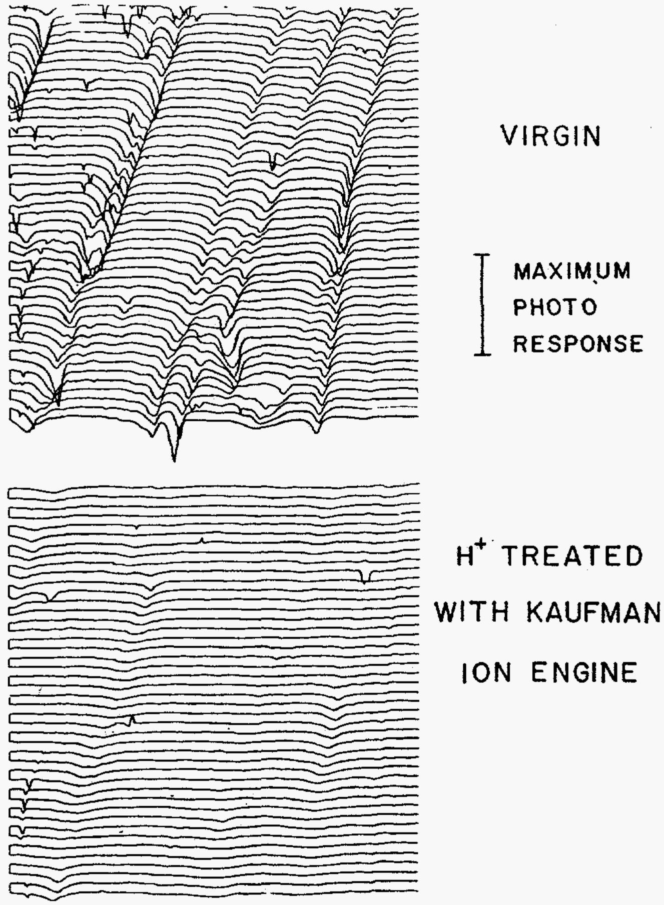
This program emphasizes the development of batteries for electrical storage in photovoltaic systems. Electrochemical batteries are currently thought to be the most attractive energy storage systems for use with photovoltaics. Improved lead-acid technology is being developed and characterized; advanced battery types to be evaluated include iron-chromium REDOX and zinc-bromine systems.

Work under way includes

- Systems analysis to define storage battery requirements
- Identification and ranking of the significant deficiencies between existing battery technology and future battery requirements
- Research and development to bring battery technology in line with future requirements

While much remains to be done to fully determine what battery performance is required or under what conditions battery storage will prove useful, it is clear that major cost reductions and improvements in the cycle life of charge and discharge must be made. A laboratory for careful battery characterization, together with real-world testing at the Photovoltaic Advanced Systems Test Facility, will contribute to the design of battery systems by industry.


Batteries under test in evaluation laboratory



These current maps show the short circuit induced in a polycrystalline silicon solar cell by electron beams. The ridges are caused by grain boundaries and reflect the strong electron-hole recombination character of these sites. Treatment of the boundaries with hydrogen removes the recombination sites and hence the short-circuit current.

Applied Research

In addition to the solar project activities already described, Sandia is also pursuing applied research on longer range solar energy technology. The research examples that follow aim to add to the fundamental understanding of possible future solar conversion devices.

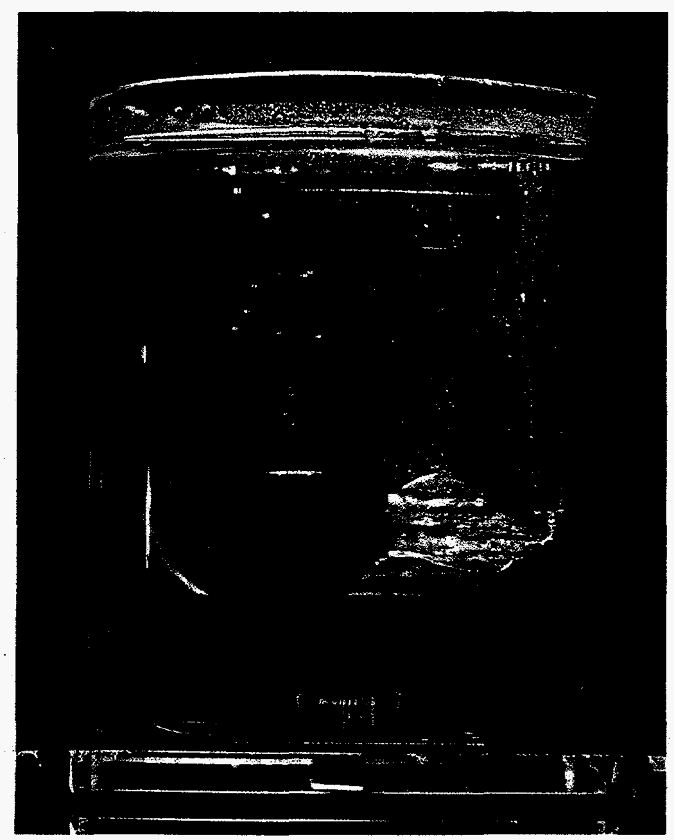
Improved Polycrystalline Materials for Solar Cells

The cost of silicon solar cells must be reduced before they can realize their full potential as a source of electrical power production. Single-crystal silicon solar cells, though reasonably efficient, are expensive to fabricate. Polycrystalline silicon (polysilicon) solar cells, on the other hand, are cheaper to produce but not very efficient largely because of the electronic effects of grain boundaries. Sandia has developed a technique for modifying the electrical properties of grain boundaries, and experiments show that grain boundary resistance can be both raised and lowered reversibly. These changes can be brought about by diffusing atomic hydrogen into the polysilicon, a technique termed "passivation." The resulting material is quite stable at room temperature. Such treatments applied to polysilicon solar cells increase carrier lifetime and improve junction characteristics, thereby greatly increasing the efficiency of photovoltaic conversion. Before the optimum polycrystalline silicon solar cell can be produced, however, the precise nature of grain boundaries must be understood.

Photoelectrolysis of Water

A second example of solar research at Sandia is the Solid State Research Department's investigation of the photoelectrolysis of water. The objective of this work is to develop a way to produce hydrogen by using a solar-illuminated semiconductor system. If this photoelectrolysis concept proves practical, it will solve one of the major problems of solar energy — the ability to store the energy produced.

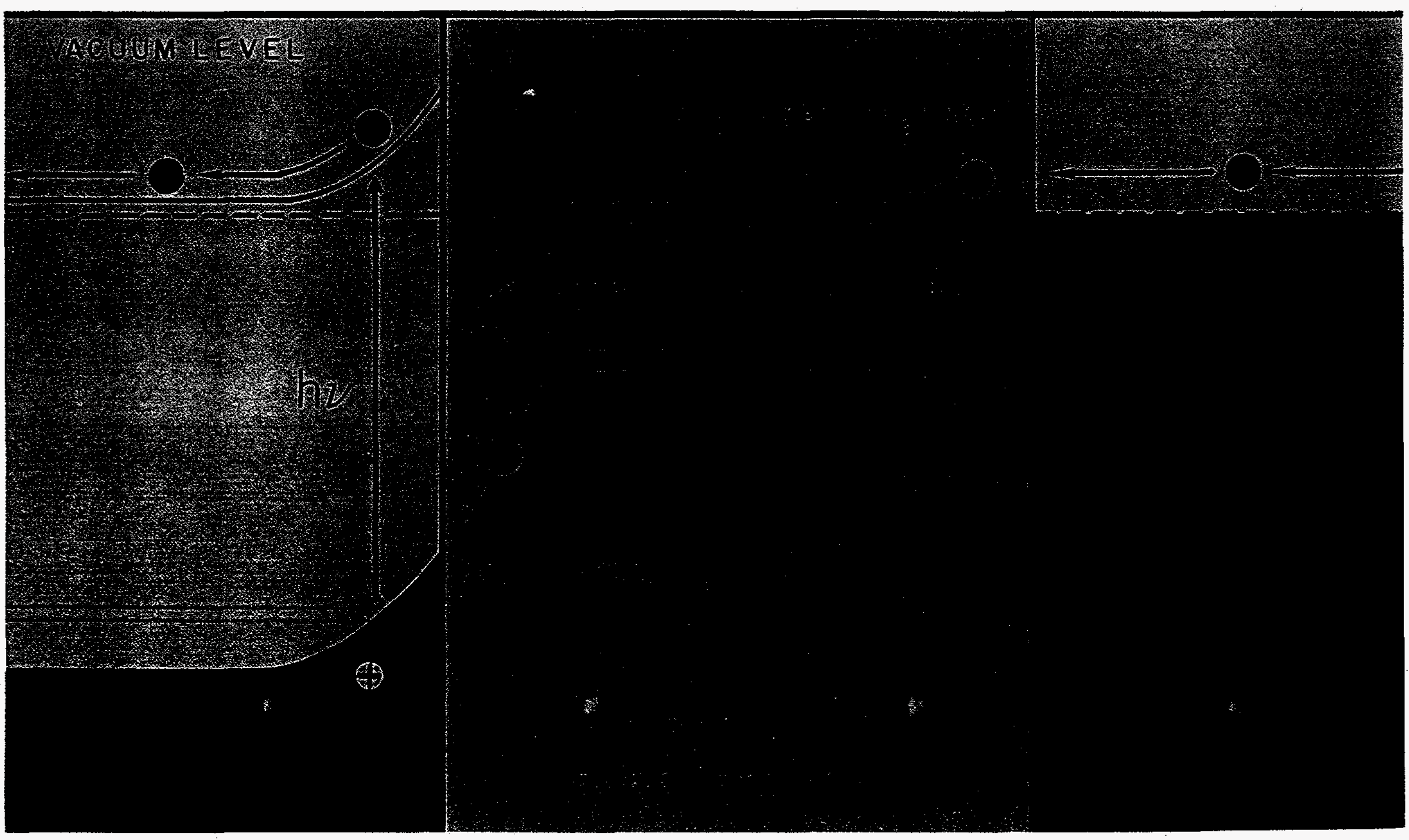
The prototype photoelectrolytic device consists of a platinum or carbon cathode connected to a semiconductor electrode, both immersed in an electrolyte (in this case, water). Solar radiation directed onto the semiconducting electrode gen-



An operating photoelectrolytic cell showing the disk-shaped semiconductor electrode and rectangular-shaped metallic cathode. The bubbles coming from the electrodes are oxygen and hydrogen erates oxygen at the surface of the electrode and hydrogen at the metallic cathode. Light with energy, hν (larger than the bandgap) pumps electrons from the valence band to the conduction region of the semiconductor. In a high-potential energy state these electrons flow through the wire to the metal cathode, where hydrogen is evolved by the reaction shown. A second reaction at the semiconductor surface fills the hole left by the light-excited electron and evolves oxygen in the process. Thus electrons are optically raised by sunlight to a high-potential energy and, as they lose this energy, change the chemical composition of the electrolyte.

We have defined critical performance factors and constructed mathematical models to describe them. Using the results obtained, we have fabricated semiconductor electrodes with enhanced performance characteristics, and these electrodes are being evaluated.

OPTICAL (SOLAR) PUMPING OF ELECTRONS



Energy-level diagram for the photoelectrolysis of water

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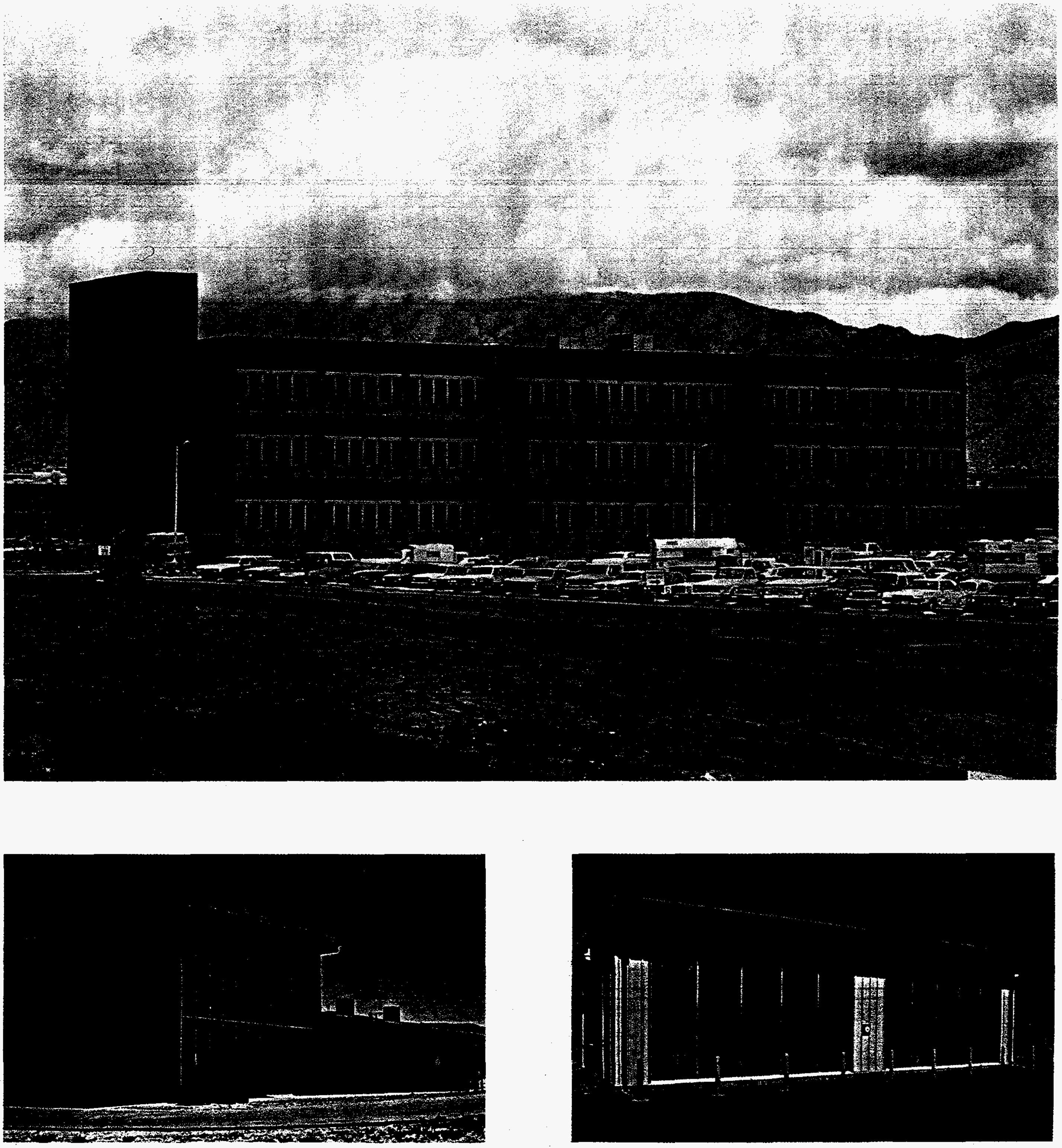

Sandia is using solar energy successfully and economically by incorporating passive solar design features in three of our new buildings — the Safeguards building, the assembly building at the CRTF, and the test facility at the PASTF.

Inquiries

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